ENERGY R&D

A Technology Status Report

RADIANT- WAVE TECHNOLOGY
As a source of energy savings

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PREPARED BY: Energy Technology Development
Section
Ontario Ministry of Energy

Ministry
of
Energy
Ontario

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RADIANT WAVE TECHNOLOGY STATUS REPORT
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EXECUTIVE SUMMARY

Radiant wave technologies include microwave, radio frequencies and infrared heating as well as ultra-violet curing devices. Unlike conventional heating equipment, where heat is applied to the surface of an object, radiant heating produces heat within the body of the material. The benefits of radiant heating technologies are lower energy costs, reduced floor space requirements, less scrap material, lower exhaust emissions, lower labour costs, greater productivity and improved product quality.

The Ministry of Energy is evaluating uses of radiant wave technology in a number of industries - ceramics, food processing, pharmaceutical, lamination and coating.

Regulatory, technical and economic impediments have been identified. A list of Canadian equipment suppliers is provided.

BACKGROUND

Radiant wave technologies include microwave, radio frequency (RF), and infrared (IR) heating as well as ultraviolet curing devices.

About 10 per cent (40,000 GWh/yr) of the energy consumed by industry in Ontario is for process heat. Less than two per cent of the process heat requirement is supplied by electricity. Although radiant wave heating has been used for over 30 years, the application of these electrotechnologies to Canadian industry has been limited.

Radiant wave technologies provide a unique opportunity for efficient energy use. The application of these technologies offers increased energy efficiency, improved product quality and increased productivity.

TECHNOLOGY DESCRIPTION

Unlike conventional heating equipment, where heat is applied to the surface of an object, radiant wave heating produces heat within the body of the process material. When material is passed through an electromagnetic field, the energy can be focused and modulated, allowing precise control of both the location and quantity of heat. In production processes, precise control translates into a minimum waste of energy, time and material.

The characteristic of the electromagnetic field is defined by the intensity (magnitude of the electromagnetic wave) and by the frequency (oscillations per second of the electromagnetic wave), which is inversely proportional to the wavelength. The electromagnetic spectrum is shown in Figure 1. Radio-frequency on the electromagnetic spectrum is represented by the region below 300 MHz corresponding to wavelengths greater than 1 M. Microwaves on the electromagnetic spectrum are in the frequency region of 300 GHz to 300 MHz with corresponding wavelengths between 1 mm to 1 meter.

The frequency of the applied field influences the depth of penetration into a material. As frequency increases, penetration depth decreases. Ultraviolet (UV), which has a very high frequency, has a small penetration depth. Infrared (IR) has a slightly higher penetration depth and microwaves, still lower in frequency, can heat to a depth of a few centimetres. Low frequency RF can penetrate to a depth of a metre or more.

In considering applications of radiant electrotechnologies, the appropriate selection of frequency provides greater efficiency and control over the applied heat. Energy is directed towards the material and not the surrounding environment.

Radiant heating refers to the capability of energy, in electromagnetic wave form, to heat materials placed within the electromagnetic field. Microwave heating occurs in the frequency range of 300 to 3000 MHz with corresponding wavelength bands of 1 cm to 1 meter. Radio-frequency heating occurs in the frequency range of 3 to 300 MHz with corresponding wavelength bands of 1 to 100 meters. Infrared and ultraviolet radiant heating have wavelengths of 100 microns to 1 mm and 100 angstroms to 1 micron respectively.

Microwave and radio-frequency heating are often referred to as dielectric heating, since most dielectric materials (non-conducting, non-metallic materials) absorb high-frequency electromagnetic energy. The absorption of energy results in the generation of heat within the material.

Dielectric Heating: Radio Frequency and Microwaves

Heat is required for many industrial processes. The disadvantage of conventional heating technologies is that the surface of the material is overheated before the centre has reached the required temperature. Microwaves and lower frequency radiowaves generate heat within the product uniformly, by causing rapid changes in the polarization of molecules. This change in polarization creates an internal friction, generating heat throughout the material, known as dielectric heating. Dielectric heating is normally used with non-conducting or insulating materials.

The two main components of a dielectric system are the energy wave source and the applicator, which transfers the energy waves to the material being heated.

Microwave sources, called magnetrons, are available in ratings up to 25 kW. Microwaves can be applied to a material in three ways: in standing wave mode, the energy is concentrated onto a small area; in multimode, microwaves hit the material from all directions; and in travelling wave mode, the microwaves can be directed down a conveyor belt. All three modes represent a particular pattern of electromagnetic energy distribution, within a confining structure, caused by the interaction of two or more travelling waves.

Radio frequency energy waves for industrial use are normally generated by triode oscillators. Applicators take the form of parallel plate for thick materials, stray field for thin materials and staggered stray field for materials of medium thickness. Precise application of the applied energy can be achieved using electronic controls.

Microwave and radio-frequency devices can provide uniform heating of many non-metallic materials. Microwave applications are generally associated with food, rubber and metal fabrication industries. Radiowave applications are generally associated with textiles, plastics, wood and paper product industries.

There are two differences between microwaves and radio frequencies for industrial use: the type of generator used to convert the 60 Hz frequency to the required operating frequency; and the procedure used to apply the energy to the product.

Infrared

Infrared (IR) energy consists of wavelengths ranging between 1 to 400 microns. The energy is almost completely absorbed near the surface of the heated material. This property makes IR ideal for certain drying and curing applications.

IR sources, which are called emitters, can take a number of forms depending on the wavelength required. As the temperature of the source is increased, more energy is provided at shorter wavelengths.

Devices that generate short infrared wavelengths include reflector heat lamps, IR guns and tubular quartz emitters. Flat quartz emitters generate medium infrared wavelengths and ceramic emitters generate long infrared wavelengths. The selection of an IR emitter for a particular application depends on the following:

- the absorption characteristics of the product
- the distance between the emitter and the product
- the time required to heat the product
- the power intensity.

Ultraviolet

Ultraviolet (UV) radiation is produced by ionizing gases in an electric arc or discharge. Mercury vapour and xenon are the most common gases and the discharge may be produced either by creating an arc between electrodes or by placing the tube containing the gas in a microwave field.

The principal application for UV radiation is in the curing of coatings, whereby a chemical reaction in the coating material creates a hard and impervious surface.

TECHNICAL STATUS

Dielectric

Dielectric heating is well established for specific applications, and has been widely used for many years.

Although the benefits of dielectric heating are known, the uptake by Canadian industry has been slow.

The following factors have contributed to the limited commercialization in Ontario:

- unfamiliarity with the technology
- relatively high equipment costs
- relatively low cost of fossil fuel.

Infrared

Infrared heating is gaining popularity in industry as an alternative to conventional air convection heating. Units are available that operate on natural gas or electricity. The heat output can be controlled precisely and directed effectively at the product being heated. This results in greater energy efficiency, enhanced product quality and increased rates of production compared to conventional heating processes.

Infrared cannot always perform the complete drying cycle. In many cases, IR could give better pre-drying than conventional equipment. Therefore, manufacturers will often provide units that combine convection and IR heating.

IR heaters can be placed out in the open plant environment, something which cannot be done with convection ovens or microwave ovens. This adds greater flexibility to assembly-line operations, takes up about one-quarter of the space of convection ovens, and the heat source can be started up and shut down quickly.

IR is also used for space heating. Efficiency results from heating objects and people, not the surrounding environment.

Ultraviolet

UV curing has been commercialized for a variety of industrial products, including:

- wood products
- plastics
- electronics
- paper products
- metal decorating.

The advantages of UV curing include the speed at which coatings dry and the suitability to heat sensitive materials.

R&D opportunities for radiant wave technologies involve the expansion of innovative applications to industry rather than technology development.

TECHNOLOGY DEVELOPMENT

The National Research Council of Canada (NRC) has been involved in microwave research and development for nearly 17 years. The Council has worked with industries to develop innovative applications such as drying films, heating blood plasma and melting ground frost to lay cables and pipes. NRC has also studied and designed systems for sealing corrugated cartons, heating and sterilizing seeds, grains and nuts, and drying inks on high-resolution graphics.

Ontario Hydro's Research Division has installed microwave and IR heating chambers to test product heating and drying. Companies can bring samples of products to test heating rates and heating/drying qualities under varying frequencies and powers of microwave or IR radiation. Other research centres such as the University of Waterloo and the Ontario Centre for Food Processing and Farm Machinery are studying and testing specific applications such as food sterilization.

The Ministry of Energy is evaluating several innovative radiant wave applications. These include:

- microwave and RF applications to lamination
- microwave drying of ceramic products
- microwave application to pharmaceuticals
- UV and IR applications to coatings
- microwave application to food processes.

The Canadian Electrical Association is interested in promoting radiant wave technologies and has commissioned studies to examine their potential.

There are a number of American and U.K. manufacturers of microwave and RF heating equipment. RF heating appears to be the most popular and well-developed in terms of systems for specific applications.

In Canada, a number of American and British firms supply IR heaters for general and specific applications. A few Ontario firms supply American equipment, including gas and electric units. A number of equipment manufacturers and suppliers are listed in APPENDIX A.

APPLICATIONS

A recent study identified 393 potential electrotechnology applications in over 100 industries in Ontario (7). Some 85 applications involved IR and 52 applications represented dielectric heating. TABLE 1 summarizes the potential application of dielectric and IR technologies to industry in Ontario.

TABLE 1

Potential Applications of Radiant Wave Technology to Industry

INDUSTRY	INFRARED	DIELECTRIC
Mining	2	-
Food	8	8
Beverage	4	4
Tobacco products	2	2
Rubber products	3	3
Plastic products	4	4
Primary textiles	3	1
Textile products	4	-
Clothing industries	3	-
Wood industries	3	-
Paper and allied products	4	-
Primary metals	2	-
Fabricated metals	9	4
Machinery industries	3	3
Transportation equipment	7	6
Electrical and electronics	9	8
Non-Metallic mineral products	4	1
Refined petroleum coal products	1	-
Chemical and chemical products	8	6

A broad range of microwave heating applications have been identified. These include:

- tempering and thawing frozen food products
- drying and cooking food
- drying agricultural products
- drying water-based adhesives
- curing foundry sand cores
- preheating and vulcanising rubber
- drying pharmaceutical products.

RF equipment has four major industrial applications: removing moisture (drying and baking); welding plastic; glueing wood; and preheating plastics.

Applications of IR processes have been predominantly the drying of water based and solvent-based inks and paints used as surface coatings. Other applications of IR heating include:

- heating sheets or moving webs of material
- removing surface water from thin materials such as fabrics and paper

A more detailed applications list is provided in Appendix B.

It is estimated that 1.2 MW of industrial microwave power are installed in Canada at present. Principle applications include the processing of rubber and food. In Canada, 2MW of installed RF equipment are used primarily within the plastics and wood products industries. IR systems in Canada account for 3.5 MW used mainly in the wood and paper products industries.

ECONOMIC STATUS

Substantial savings to industry come from increased production capabilities due to accelerated drying times and reduced costly floor space. In contrast to conventional process heating equipment, radiant wave technology results in a capital cost reduction of 25-35 per cent when all factors are considered. Energy savings are usually substantial, but generally represent half the increased revenue from the additional production using microwave equipment.

Repair and maintenance costs for microwave systems tend to be high. A magnetron may have to be replaced after 6000 hours of operation. Maintenance costs tend to be 20-30 per cent greater for microwave systems requiring highly skilled service technicians. Overall savings in production costs attributed to microwave systems over a 10-year period are estimated at 10 per cent; however, depending on the industrial application, an overall savings of 35 per cent can be achieved.

STAKEHOLDERS

(a) Technology users from all sectors of industry would be interested in energy-efficient processes.

(b) Ontario Hydro is interested in the efficient application of electricity in the province.

(c) Government, particularly the Ontario Ministry of Energy, is interested in encouraging a more efficient use of energy.

BENEFITS

Dielectric Heating

Dielectric heating and drying applications offer the following distinct advantages over conventional heating systems:

- reduced energy cost
- increased productivity
- increased product quality
- reduced scrap material
- reduced floor space requirements
- reduced labour costs
- reduced exhaust emissions.

The most significant benefits of using radiant heating instead of conventional heating are savings in energy and money. In general, the effectiveness of radiant heating (the amount of heat delivered to the product over the total amount of energy consumed by the heater) is in the range of 50 to 60 per cent. The most competitive alternative is natural gas fired convection, which can range in effectiveness from 10-25 per cent.

The greater appeal to industry lies in the better control over quality and production rate.

Some processes favour radiant wave heating. Examples are rubber curing and sand core drying. Here, large ovens, which require time and energy to start up, are traditionally used. According to manufacturers' claims in rubber curing, gas heating requires 7 MJ/Kg (3,000 Btu/lb) whereas microwave heating requires only 1.4 MJ/Kg (600 Btu/lb).

In some instances, the economics of the situation may dictate greater energy use in order to achieve a higher-quality product.

IMPEDIMENTS

Regulatory

Some concerns about the safety of electromagnetic radiation still persist despite regulations that protect against leakages of radiation. The occupational exposure standard in the 10-1000 MHz frequency range is 1 mW/cm^2, whereas exposure standards for the general public are restricted to 1 mW/cm^2 in the 0.01 to 300 GHz range.

Technical

The following are some of the technical impediments to the use of radiant heat:

(a) Lack of information on the potential of radiant heating - Not all potential users are up-to-date on the application and economic possibilities.

(b) Lack of equipment manufacturers in Canada - Reliance on imported equipment raises the capital costs.

(c) Lack of industry infrastructure for sales and service in Canada.

(d) Lack of sufficient demonstration facilities in Ontario - Demonstrations help greatly in building user confidence in equipment.

Economic

An economic impediment for many companies may be the large initial capital outlay for new equipment to replace obsolete equipment. Industry usually demands short payback periods for new equipment, and often avoids equipment with a high capital cost to minimize capital outlays.

OUTLOOK

Radiant wave technology shows benefits compared to conventional heating in production, quality control and energy efficiency. This technology is near commercialization outside of Canada. The impediments to widescale adoption in Ontario are those common to many new technologies.

Electrical utilities see the benefits of promoting electrotechnologies to encourage more efficient use of electricity. Their testing facilities will help to overcome technical impediments.

Information transfer activities and technical demonstrations of new and viable applications will help to overcome technical and economic impediments.

The Ontario Ministry of Energy facilitates the development and implementation of radiant wave technologies by:

- supporting R & D activities
- bringing together industrial stakeholders and research facilities
- supporting the development and demonstration of economically and technically viable applications in industry.

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(4) Electricity and Industrial Productivity - A Technical and Economic Perspective, P.S. Schmidt. EPRI Report FM-3690 Pergamon Press.

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(6) "The Application of Electric Infrared Heating to Industrial Processes." - London, British National Committee for Electroheat, 1981.

(7) Giffel's Industrial Steam Substitution Study. Ontario Hydro, (1985).

APPENDIX A

RADIANT HEAT SUPPLIERS

Infrared

Caloritech Division
Casah Heating Systems Inc.
220 Wyecroft Road, Unit 50
Oakville, Ontario
L6K 3V1 (416) 842-8344
Robert Kennery, Manager - Sales & Marketing
- Infrared for process and space heating
- Designs and manufactures all types of industrial heaters, boilers and heat transfer systems.

Infra Ray Inc.
P. O. Box 1803
367 Cochrane St.
Port Perry, Ontario
L0B 1N0 (416) 985-8414
Robert Wood
- Infrared for space heating
- Distributes Solaronic electric, gas and IR heaters

Davis Energy Systems Ltd.
25 Birmingham St.
Toronto, Ontario
(416) 259-9235
- Infrared for space heating
- Supplies electric and gas fired IR space heaters

Drypoll Inc.
131-40 Maple Ave.
Flushing, New York 11355
(718) 353-3426 Eduard Zimmermann, President
- Infrared for process heating
- Designs and manufactures IR heaters, thermoforming machines and gas or electric ovens

Davis Energy Group
2655 Portage Bay Ave., Suite 1
Davis, California 95616
(916) 753-1100 Richard Bourne, President
- Radiant floor heating
- Designs heating and cooling systems for all sectors

Hamilton Procelains Limited
25 Campbell St.
Bcx 594
Brantford, Ontario
M3T 5N9
Mr. R. G. Robb, Director of Research
- Gas and IR heating equipment

Chromolox Canada Ltd.
210 Rexdale Blvd.
Rexdale, Ontario
M9W 1R4
K. Williamson, Industrial Sales Applications
- Infrared devices for process and space heating.

Radiant Heat Enterprises Inc.
P.O. Box 566
Passaic Ave. and Pier Lane West
Fairfield, New Jersey 07006
(201) 227-6633 Steven Na, President
- Infrared for industrial processes
- Designs and manufactures IR heaters and IR, gas and electric ovens

Argus International
P.O. Box 38
Hopewell, New Jersey 08525
(609) 466-1677 Bernard Laucius, Applications Engineer
- Infrared and ultraviolet
- Designs and manufactures IR heaters and ovens and ultraviolet processors

Microwave and Radio Wave:

Firing Industries Ltd.
P.O. Box 596
St. Catharines, Ontario
L2R 6W8 (416) 688-0962
Daniel J. Feasby
- Microwave vacuum dryers
- Manufactures and supplies a number of processors and machines including conveyors, crushers, dryers, evaporators, heat exchangers, mixers, mainly for specialized processes

Mega System Design Limited
1766 Midland Ave., Scarborough
M1P 3C2 (416) 751-1935 Mr. K. Fraser, President
Custom microwave systems
- Industrial heating and drying

Thermatron Thermex
60 Spence St.
Bay Shore, New York 11706
(516) 231-7800 John Hokanson, Marketing Manager
- Microwave and radio wave heating

Glenro Inc.
39 McBride Ave. Ext.
Paterson, N.J. 07501
(201) 279-5900 Jim Alimena, marketing
- Infrared and ultraviolet
- Designs and manufactures IR heaters and ovens and ultraviolet processors

J. A. Callanan Co.
5677 Northwwest Highway
Chicago, Illinois 60646
(312) 792-3344 J. Callanan
- Radio wave heat sealing
- Designs and manufactures radio wave heat sealing equipment

PSC Inc.
21751 Tungsten Rd.
Cleveland, Ohio 44117
(216) 531-3375 John Zimmerly
- Radio wave industrial heating

Radio Frequency Co.
150 Dover Road
P.O. Box 158
Millis, Massachusetts 02054
(617) 762-4900 Thomas James, President
- Radio wave industrial heating

Raytheon Company
Foundry Avenue
Waltham, Massachusetts 02259
(617) 899-8400
Richard Edgar, Manager Industrial Equipment Group

Cober Electronics Inc.
102 Hamilton Ave.
P.O. Box 10032
Stamford, Connecticut 06904
(203) 327-0003 Vincent Gaccione, Marketing Manager
- Microwave heating and cooking
- Designs and manufactures industrial microwave heating equipment and microwave communications and radar equipment.

Microdry Corp.
3111 Fostoria Way
San Ramon, California
(415) 837-9106
- Microwave heating, drying and cooking
- Designs and manufactures microwave equipment for industrial processing

Victrix Limited
Box 1807, Guelph, Ontario
N1H 7A1 (519) 836-1480
NB. (613) 592-3888 (Kanata, Ontario)
Mr. C.B. Dowden, Vice President Engineering
Manufacturing of microwave heating and drying equipment

APPENDIX B

USERS AND APPLICATIONS

Microwave and Radio Wave

1. Food and Beverage and Tobacco Industries
   Existing - Pre-cooking and cooking; dough raising and baking; thawing; drying cereals, nuts and tobacco
   Examples - Bacon/sausage cooker
   Developmental - Food sterilization and preservation, pest control, grain drying.

2. Rubber, Plastic and Glass Industries
   Existing - Rubber heating and curing; plastic and glass sealing, bonding and heating
   Examples - Plastic preheater, epoxy curing, rubber processing systems.

3. Clothing and Fabrics Industry
   Existing - Drying leather, wool, textiles and fibres; dye fixation and sealing of materials
   Examples - Textile products and package dryer.

4. Wood and Paper Industries
   Existing - Wood and chip drying; paper and pulp drying; ink and varnish drying; sealing of envelopes, cartons, tubes.
   Examples - Drying and sealing of envelopes/forms.

5. Metals Industry
   Existing - Drying of coating on sand cores
   Examples - Conveyor ovens.

6. Printing Industry
   Existing - Drying of photographic prints, highway paint stripes
   Examples - Interdigital line dryer.

7. Chemical Industry
   Existing - Drying mixtures and sterilizing drugs
   Examples - Granule material dryer.

8. Mineral Products Industry
   Existing - Road pavement revamping, ceramic block drying
   Example - Pavement heater.

Infrared

1. Food and Beverage Industry
   - Warming of fast food products, thawing of frozen vegetables and potato peeling
   Examples - Conveyorized ovens.

2. Fabric Industry
   - Pre-drying and setting nylon, setting dyes onto polyester, curing resin finishes and thread bonding
   Examples - Vertical textile predryer, infrared oven, predryer/heat setter.

3. Rubber and Plastic Industry
   - Curing or shaping rubber and plastic; annealing polypropy- lene, nylon, polyester, monofilaments and films; drying and fusing PVC coatings, and vinyl coverings; drying coated wire
   Examples - High-speed shrink tunnel, drying and annealing ovens.

4. Metal, Machinery and Electrical Industries
   - Baking paints; testing aircraft structures; drying coatings and printing on cans, metal parts and printed circuit boards, soldering printed circuit boards
   Examples - Conveyorized ovens, soldering oven.

5. Paper and Printing Industries
   - Drying and curing resins in paper, drying adhesive paper, pre-drying before paper-making machine and drying of inks and paints
   Examples - Web processing.

6. Chemical Industry
   - Drying of chemicals and tablets
   Examples - Tablet dryer.

7. Miscellaneous
   - Space heating

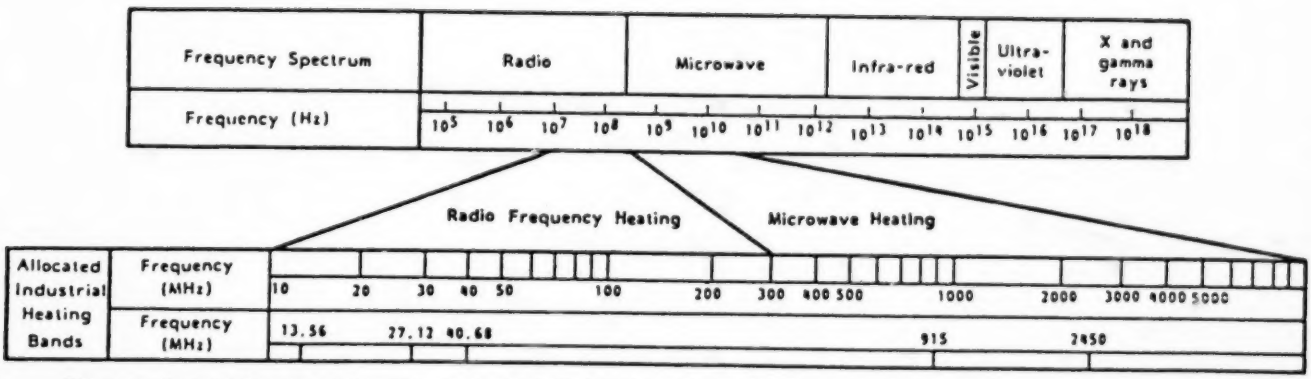

Figure 1 - The electromagnetic spectrum showing the location of industrial microwave and radio-frequency heating regions.

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